SECTION IX

CONTRIBUTIONS FROM NON-POINT SOURCES AS CALCULATED FROM UNIT AREAL LOADING DATA

A. UNIT AREAL LOADING METHODOLOGY

The majority of the annual nutrient load contributed to lakes in rural and semi-rural watersheds originate from nonpoint sources (Dillon and Rigler, 1975). Overland runoff of stormwater has been demonstrated to be the primary vehicle of such nutrient/sediment loads (Uttormark, 1979).

The National Eutrophication Survey of Lake Hopatcong concluded that the majority of nutrient and sediment contributions to Lake Hopatcong originate from nonpoint sources (USEPA, 1976). In order to more accurately quantify the magnitude of nonpoint source loads and investigate the relationship between land use practices and nutrient/sediment export, a detailed sub-basin analysis of land use-unit areal loading was conducted.

Estimates of the annual load of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) entering the lake via nonpoint sources, were calculated using unit areal loading (U.A.L.) methodology (Uttormark, et al, 1974, USEPA, 1980). Annual nonpoint source loads were calculated for the entire watershed. Loads were calculated for each sub-basin (Table 23), and each land use category (Table 24), in order to quantify their relative contributions to the total nonpoint source load.

Table 23

NON-POINT UNIT AREAL LOAD (kg yr^{-1}) OF TOTAL PHOSPHORUS, TOTAL NITROGEN AND TOTAL SUSPENDED SOLIDS TO LAKE HOPATCONG

Sub Basin	Area (ha)	TP Load	% Total	TN Load	% Total	TSS Load	% Total
1	853.1	190.8	7.9	2564.2	8.2	266700	6.2
2	769.7	204.0	8.5	2504.4	8.0	332600	7.7
3	69.6	41.4	1.7	314.6	1.0	96030	2.2
4	266.3	64.1	2.7	815.1	2.6	96445	2.2
5	233.1	69.3	2.9	791.7	2.5	122230	2.8
6	213.3	81.8	3.4	796.6	2.5	164170	3.8
7	106.4	78.4	3.3	561.6	1.8	192150	4.5
8	356.1	88.4	3.7	1101.4	3.5	137150	3.2
9	175.2	53.5	2.2	614.1	2.0	97050	2.3
10	111.7	33.4	1.4	433.0	1.4	66075	1.5
11	168.4	59.7	2.5	595.7	1.9	117175	2.7
12	90.2	55.9	2.3	421.4	1.3	132575	3.1
13	128.3	41.3	1.7	435.8	1.4	76700	1.8
14	176.9	51.1	2.1	576.8	1.8	88850	2.1
15	105.2	41.2	1.7	388.1	1.2	84400	2.0
16	183.3	89.7	3.7	751.1	2.4	199475	4.6
17	45.3	30.8	1.3	223.4	0.7	74525	1.7
18	15.0	3.7	0.2	43.5	0.1	3060	0.1
19	12.1	2.6	0.1	35.1	0.1	2805	0.1
20	142.0	79.3	3.3	583.5	1.9	183300	4.3
21	20.0	16.5	0.7	116.1	0.4	41100	1.0
22	161.1	68.0	2.8	630.2	2.0	143425	3.3
23	54.2	27.3	1.1	226.0	0.7	60230	1.4
24	37.2	25.2	1.1	188.7	0.6	59300	1.4
25	22.7	11.4	0.5	94.1	0.3	25450	0.6
26	30.4	15.6	0.7	127.7	0.4	35250	0.8
27	169.6	124.1	5.2	895.5	2.9	303715	7.1
28	56.7	47.1	2.0	322.5	1.0	113025	2.6
29	76.5	55.7	2.3	407.9	1.3	135405	3.1
30	15.0	10.8	0.5	76.0	0.2	26500	0.6
31	33.2	17.2	0.7	142.9	0.5	37505	0.8
32	117.4	51.9	2.2	476.1	1.5	110645	2.6
33	148.1	76.3	3.2	637.0	2.0	171925	4.0
34	93.9	69.3	2.9	487.6	1.6	169950	4.0
35	198.3	133.2	5.6	981.6	3.1	318975	7.4
36	27.1	11.7	0.5	115.6	0.4	21545	0.5
Fallout on Lake		271.8	11.3	10870.0	34.6	--	--
TOTAL	5482.8	2392.8		31346.6		4303460	

Table 24

NON-POINT UNIT AREAL NUTRIENT AND SEDIMENT LOAD (kg yr^{-1})
TO LAKE HOPATCONG SUMMARIZED BY LAND USE CATEGORIES

Annual Load (kg yr^{-1})

Parameter	Residential			Open Areas					
	High	Low	Commercial	Covered	Exposed	Forest	Dry Fall-out on Watershed	Dry & Wet Fallout on Lake	Total
Total Phosphorus	1083.8	16.8	217.2	7.5	7.8	775.7	11.0	271.8	2391.6
Total Nitrogen	6773.5	167.8	1448.0	125.5	129.0	9695.5	2193.1	10870.0	31402.4
Total Suspended Solids	2709400	13420	579200	10040	25800	969550	--	--	4307410

In most cases, mean loading coefficients (Uttormark et al., 1974, USEPA, 1980) were used (Table 25). Open-covered land use was ascribed the same loading values as range-pasture land. Open-disturbed land use was ascribed the same nutrient loading values as agricultural land, but the total suspended solids loading coefficient was increased to 2000 kg yr^{-1} to account for the more erodable nature of exposed soils.

A more accurate assessment of loading from urban land was achieved by developing specific loading coefficients for the major types of urban land use. From the available range of urban loading coefficients (Table 25), unit areal loading relationships were selected for high density residential, and commercial applications. Loading coefficients were developed which best reflected the influence of population density, impervious surfaces, vehicular traffic, storm sewers, etc. on the loads eminating from these urban land use categories. The mean urban loading coefficients were used for the high density residential categories, whereas the minimum urban loading coefficients were used for low density residential applications. Commercial land was assigned loading coefficients double the mean urban loading values. The use of these modified export coefficients appear more appropriate than lumping these categories under a single land use heading as is done by using the average EPA loading coefficient.

Nutrient loads entering the lake via direct precipitation and dry fallout into the lake itself, and by dry fallout onto the watershed were also estimated using average loading coefficients.

Throughout the entire 5482.7 ha watershed, less than 5 ha are actively farmed. As these lands are scattered throughout the watershed their contribution to the nutrient and sediment load of the lake is not very great. No steps were taken to develop agricultural loading coefficients. Rather, these lands were included in the open-covered category.

Table 25

APPROXIMATE RELATIONSHIP BETWEEN LAND USE
AND UNIT AREAL LOADING FROM NONPOINT SOURCES

	Average ($kg\ ha^{-1}\ yr^{-1}$)			Range ($kg\ ha^{-1}\ yr^{-1}$)			As Used in This Study ($kg\ ha^{-1}\ yr^{-1}$)		
	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS
Forest[a]	2.5	0.2	250	1-10	0.005-1	40-400	2.5	0.2	250
Range/Pasture[a]	5	0.3	400	2-10	0.2-0.6	10-1,000	5.0	0.3	400
Cropland[a]	10	0.6	1,600	1-40	0.03-0.7	300-4,000	10.0	0.6	1,600
Urban[a]	5	0.8	2,000	2-20	0.25-5	200-5,000	SEE TEXT FOR DETAILS		
Feedlots[a]	1,000	250	--	700-1,500	100-400	--	1,000	250	--
Precipitation[b,c]	10	0.25	--	1-100	0.25-1	--	10.0	0.25	--
Open-Disturbed[d]							10.0	0.6	2,000
Open-Covered[e]							5.0	0.3	400
Dryfall on Water-shed							0.4	0.002	--

[a]Applied to watershed area.

[b]Applied to lake surface area.

[c]For 102 cm (40") per year.

[d]Assumed same as agricultural application, but ascribed higher TSS value to account for lack of cover.

[e]Assumed same as range/pastureland.

FROM: Clean Lakes Program Guidance Manual EPA 440/5-81-003, 1980.

Sub-basins 1 through 4 drain into Lake Shawnee, a headwater of Lake Hopatcong. In all lakes, a certain fraction of the nutrients and sediments which enter the lake will be retained due to settling. The amount of material which is retained is a function of the lake's hydrology, particularly its flushing rate. Lakes with prolonged hydraulic retention (i.e. infrequent flushing) have a greater propensity to retain materials as a result of sedimentation. In order to accurately calculate nonpoint source loading to Lake Hopatcong, it was necessary to account for retention by Lake Shawnee. Emphasis was placed on calculating phosphorus retention due to that nutrient's important role in the accelerated eutrophication of lakes. Equation 2 (Ostrofsky, 1978) was used to compute phosphorus retention. A value of 0.406 was obtained (Table 26). Thus the nonpoint source TP loads for sub-basins 1 through 4 were multiplied by (1.0-0.406) to account for the sedimentary loss of TP in Lake Shawnee.

The annual U.A.L. loads for TP, TN, and TSS were obtained by first calculating the loads exported from each land use for each sub-basin. By summing the sub-basin contributions, the total loads generated by all nonpoint sources in the watershed were obtained (Table 27).

Table 26

PHOSPHORUS RETENTION IN LAKE SHAWNEE

Empirical Calculation Using Ostrofsky Model (1978):

$$Rp = 0.201e^{(-0.0425qs)} + 0.5743e^{(-0.00949qs)}$$

where: Rp = Phosphorus retention

$$qs = \text{Areal water load} = \frac{\text{Annual Discharge } m^3\ yr^{-1}}{\text{Lake Surface Area } m^2}$$

Annual Discharge from Lake Shawnee* = $9.0 \times 10^6 m^3 yr^{-1}$

Surface Area of Lake Shawnee** = 20.2 ha

$$qs = \frac{9.0 \times 10^6 m^3 yr^{-1}}{202{,}000\ m^2} = 44.6\ m\ yr^{-1}$$

$$Rp = 0.201e^{(-0.0425)(44.6)} + 0.5743e^{(-0.00949)(44.6)}$$

$$Rp = 0.030 + 0.376$$

$$Rp = 0.406$$

% TP Retention = <u>40.6</u>

*Source: Calculated empiracally, verified using USEPA, 1976, NES Report
**Source: Sussex County, NJ 208 Water Quality Management Plan

Table 27

NUTRIENT-SEDIMENT INPUTS TO
LAKE HOPATCONG AS CALCULATED WITH THE
UNIT AREAL LOADING MODEL

U.A.L. Model

$$Mj = \sum_{i=1}^{n} \left[\Sigma a(ha) + \Sigma b(ha) = \Sigma c(ha) + \Sigma d(ha) + \Sigma e(ha) + \Sigma f(ha) + \Sigma g(ha) + \Sigma h(ha) \right]$$

Mj = Annual load for TP, TN, TSS; kg yr^{-1}

a···h = loading coefficient for specific land use; kg $ha^{-1}yr^{-1}$ summed for each sub-basin

a = High density residential
b = Low density residential
c = Commercial
d = Open area, covered
e = Open area, exposed
f = Forest
g = Dryfall on watershed
h = Dryfall - precipitation directly into lake

ha = area of land use; hectares

ANNUAL NONPOINT SOURCE LOAD

Total Phosphorus*	2188.9 kg yr^{-1}
Total Nitrogen	31402.4 kg yr^{-1}
Total Suspended Solids	4307410 kg yr^{-1}

*Adjusted to account for phosphorus retention in Lake Shawnee

B. NON-POINT SOURCE LOADING TO LAKE

The U.A.L. nonpoint source TP and TN loads were found to be very different than the nutrient loading estimates generated by the EPA in its 1976 survey of Lake Hopatcong (USEPA, 1976) (Appendix A). The annual TP and TN nonpoint source loads as calculated using U.A.L. methodology are 2188.9 kg yr^{-1} and 31,402.4 kg yr^{-1}, respectively (Table 27). In comparison, the EPA calculated nonpoint source loads for TP and TN are 625 kg yr^{-1} and 40,875 kg yr^{-1}.

It should be noted, that the TSS load predicted for the basin is conservative. Soil loss will be greater in construction sites and open-disturbed areas where the vegetative cover has been removed.

Individual sub-basin nutrient loads range frorm 2.6 kg yr^{-1} to 204.0 kg yr^{-1} for TP, and 35.1 kg yr^{-1} to 2564.2 kg yr^{-1} for TN. This variability is related to differences in the size and the predominate land use activity in each sub-basin. In general, those sub-basins which are predominately urban contribute greater TP and TN loads per hectare than other land use categories. This indicates the importance of watershed urbanization on nutrient/sediment loading to lakes. As the area of impervious surfaces increases, so does overland sheet runoff and the storm water transport of materials to the receiving water body. This results primarily from the loss of natural areas for water percolation and nutrient retention.

Although the U.A.L. data serve as a preliminary estimate of existing nonpoint nutrient/sediment loading, the true utility of the U.A.L. approach is in its use in quantifying changes in nutrient loading which result from changes in watershed land use. In this manner, increases in nutrient loading resulting from further watershed urbanization can be determined fairly easily (Souza and Perry, 1977). These data suggest that a substantial amount of phosphorus and nitrogen compounds are entering the lake from nonpoint sources. In addition, the majority of the load is probably transported to the lake or its tributaries via stormwater runoff.

SECTION X

CONTRIBUTIONS FROM NON-POINT SOURCES AS CALCULATED FROM STORM AND BASELINE TRIBUTARY LOADS

A. STREAM MONITORING PROGRAM

Physical and chemical data collected from 8 major tributaries over the 12 month study period are presented in Appendix B. These data represent the physical and chemical properties of the lake's major tributaries under various flow conditions, including storm events.

1. Gaged Streams

Due to drainage patterns in the Lake Hopatcong watershed, it was possible to gage inflow to the lake at only two locations, LHS 4 and the spillway of the Lake Shawnee Dam, LHS 2 (Figure 4). The sub-basins drained by the gaged tributaries represent approximately 38% of the total watershed. Flows were monitored at the gaged stations from March 1982 through July 1982. A 90^{o}, V-notch weir was erected at LHS 4. Weir readings were converted to discharge (m^3d^{-1}) using the appropriate discharge formula (Anon., 1978). Discharge from Lake Shawnee was computed from head height measurements taken at the lip of the spillway, and converted to discharge (m^3d^{-1}) using a modified broad crested weir formula (Table 28).

2. Non-Gaged Streams

Non-gaged tributary discharge was calculated using an empirical precipitation-stream discharge formula (Table 28). Rainfall was measured with a "Clear-View" rain gage and monitored by LHRPB personnel. This rainfall data was verified through comparison with NOAA Climatological Department rainfall data measured for the general Lake Hopatcong area (NOAA, 1981-1982). These data proved to be in close agreement. Monthly rainfall data was substituted into the empirical discharge formula, along with the watershed area of each tributary, and a runoff coefficient, calculated as per Dunne and Leopold (1978), to yield the monthly discharge from each tributary. The sum of these data represents the annual tributary hydrologic contribution to the lake as measured from August 1981 to August 1982. Flows were normalized as per USEPA, 1975 (Table 28).

Table 28

PERTINENT EQUATIONS USED IN THE
CALCULATION OF TRIBUTARY CONTRIBUTIONS

Equation 6

Calculation of discharge from a 90° V notch Weir

Discharge (ft^3s^{-1}) = $2.50H^{5/2}$

where: H = gage height of water passing through weir
(converted to m^3s^{-1} using 0.02832 conversion factor)

Equation 7

Modified Broad Crested Weir Formula for the Calculation of Discharge over the Lake Shawnee Spillway

Discharge (ft^3s^{-1}) =

where: H =
(converted to m^3s^{-1} using 0.02832 conversion factor)

Equation 8

Empirical Precipitation - Stream Discharge Equation

Q = ABC

where: Q = Discharge
A = Area of Watershed ($m^2 \times 10^4$)
B = Monthly Precipitation ($m \cdot month^{-1}$)
C = Runoff Coefficient

Table 28 (continued)

Equation 9

$$\text{Annual load} = 74.604\ \bar{c}\ ys \sum_{1}^{12} NF_i$$

where: $\bar{c}$ = mean nutrient concentration of sampled stream

NF_i = normalized flow for i th month

$y = 10^{b(\overline{\log NF} - \overline{\log MF})}$

$S = \sum_{1}^{12}(NF\ 10^{b(\log NF_i - \overline{\log NF})}/12 \sum_{1} NF_i$

$\overline{\log NF}$ = mean log normalized flow

$\overline{\log MF}$ = mean log monthly flow for year sampled

b = average adjustment regression coefficient for TP and TN calculated for Northeastern United States

b = 0.06 for TN

b = 0.11 for TP

B. NON-POINT LOADING TO LAKE

Nutrient loads were calculated for gaged and non-gaged tributaries. The concentration of total phosphorus (TP) and total nitrogen (TN) was measured at each of the sampled tributaries on a monthly basis. These data were used in conjunction with the normalized discharge data to compute the annual TP and TN tributary loads (Table 29). Loads were obtained by multiplying the normalized monthly discharge data and the measured mean monthly TN and TP concentration to yield the mean monthly TN and TP load.

As point sources discharge upstream of LHS 2 and LHS 8, the nutrient loads calculated for these tributaries represent both point source and non-point source loading. In addition, an unpermitted discharge from a gravel slurry processing operation was discovered at the headwaters of LHS 4. The loads eminating from this tributary, particularly the sediment load, is affected by this point source.

The total phosphorus and total nitrogen loads contributed by the monitored tributaries are 576.621 kg TP yr^{-1} and 11628.4 kg TN yr^{-1}. There are additional tributaries which were not monitored during the course of this study. The loads contributed by those tributaries are accounted for in the U.A.L. computed non-point source loads (Section XII).

It is recognized that the nutrient loads generated using the above methodologies probably have an inherent average absolute error of 14% (Scheider, et. al., 1979). However, these calculated values are the best available estimate of nutrient loading to Lake Hopatcong. Although these loads are roughly double those computed in the N.E.S. study, they appear to be much more representative of tributary related nutrient flux to Lake Hopatcong.

Table 29

NUTRIENT CONTRIBUTIONS FROM
MONITORED TRIBUTARIES

ANNUAL NUTRIENT LOAD (kg yr^{-1})

Stream Station*	Total Phosphorus**	Total Nitrogen**
2	270.5	4928.1
3	33.5	875.4
4	71.6	1136.5
5	19.6	179.3
6	24.5	1915.1
7	68.6	1264.4
8	86.2	1329.5

*See Figure 4 for station locations.

**2 and 4 calculated using measured stream flow and measured mean monthly nutrient concentrations. Remaining stations load calculated using empirically derived flow and measured mean monthly nutrient concentrations.